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POLARIZATION OBSERVATIONS OF JUPITER AT DECAMETER-WAVELENGTHS

By

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ABSTRACT

The polarization of radiation from Jupiter has been studied during 1963 at frequencies of 16, 18, 22 and 26 Mc/s. Data has been analyzed burst-by-burst and the results are tabulated in detail for 3,800 bursts. Histograms of occurrence probability and numbers of bursts have been prepared for each frequency. In general, for the period of the observations, most of the radiation at 22 and 26 Mc/s was right-handed polarized whereas at 16 and 18 Mc/s an appreciable proportion of bursts were left-handed. In particular, bursts observed when $300 < \lambda_{III} \leqslant 360$ (I.A.U. revised System III) were found to be, respectively, 41% and 30% left-handed at 16 and 18 Mc/s.

The changes in polarization mode observed from one frequency to another may indicate magnetic and ionospheric conditions on Jupiter and allow parameters to be deduced to within quite narrow limits. This procedure is discussed in detail and it is pointed out that axial ratio, not necessarily

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a very significant quantity when observed at an antenna on the Earth, need not be calculated.

It is suggested that daily polarization variations may be due to magnetic disturbances on Jupiter and thus associated with solar activity; also, that a search should be made for long term variations caused by changes in the electron density of the Jovian ionosphere and associated with the sunspot cycle.

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I. Introduction

The polarization of the decameter-wave radiation from Jupiter was first studied by Franklin and Burke (1958), and by Carr et al. (1961). Both groups found that at 22 Mc/s most of the noise bursts were right-handed elliptically polarized (R.H.) in the radio convention of looking along the direction of propagation. A single observation by Gardner and Shain (1958) showed a similar result at 19.6 Mc/s. As R.H. polarization had been observed at stations in both the northern and the southern hemispheres it was concluded that this polarization was due to conditions on Jupiter and was not an effect of the terrestrial ionosphere. During the 1961 apparition, however, a few rather crude observations by Barrow (1962), at 18.3 and 24 Mc/s, suggested that a smaller porportion of R.H. bursts were to be found at 18.3 Mc/s than at 24 Mc/s. The following year several observers found variations in the polarization at lower frequencies. According to Carr (1962) a number of bursts recorded at 16 Mc/s showed L.H. polarization whereas at 22 Mc/s the bursts were almost exclusively R.H. L.H. polarized bursts were also observed at 16 Mc/s by Barrow (1963). Dowden (1963), working at 10.1 Mc/s, found that not only were some of the bursts L.H. but also, that the variations in polarization mode appeared to be correlated with System III central meridian longitude. Sherrill and Castles (1963), using a system which could be tuned manually to successive different frequencies in the range 15 to

24 Mc/s, observed varying proportions of L.H. bursts at frequencies below 22 Mc/s.

II. Equipment

During the 1963 apparition, observations of the polarization of radiation from Jupiter were made simultaneously at frequencies of 16, 18, 22 and 26 Mc/s. The four polarimeters were identical and each consisted of two crossed five-element Yagi antennas mounted on 35 ft. towers. Each pair of Yagis was mounted on a common boom which could be pre-set to any required altitude and motor driven in azimuth. Tracking was done in steps every half-hour so that Jupiter could be kept within a few degrees of the axis of the antenna for some four hours each night. During the period of the observations the declination of Jupiter was close to 4° corresponding to an altitude of 64° at meridian transit which occurred during the early morning hours.

A semi-conductor switching system was used to identify the polarization. This is shown schematically in Figure 1. The feed line from one Yagi is a quarter-wave longer than the feed line from the other which leads to a series half-wave switch of the type described by Smith, F. G. (1961). Thus the inputs from the two Yagis are combined at the receiver with an effective phase-difference of $\pm$ $\pi/2$ alternately. A second switch directs the audio output from the receiver alternately to two channels of a high-speed pen recorder. Both switches are driven synchronously by a multivibrator operating at about 200 c/s so that one recorder channel is L.H. sensitive and the other is R.H. sensitive. This arrangement allows circularly and elliptically polarized noise bursts to be distinguished from randomly and linearly polarized bursts. Two coincident oppositely polarized circular bursts could not be distinguished from random-linear polarization, however.

If it is assumed that the radiation is completely polarized, comparison of the L.H. and R.H. channels will allow the axial ratio of the incident wave, as well as the sense of rotation to be determined. Roberts (1963) has pointed out that the radiation may, alternatively, consist of a circular component plus a random component in which case it would be necessary to measure the random component in order to specify the degree of polarization. According to Dowden (1963), however, this measurement would be difficult at decameter-wavelengths as Faraday rotation is large and is both frequency and time dependent. Dowden, therefore, in common with Carr et al. (1961) and Sherrill and Castles (1963), assumes that the radiation is completely polarized and presents some of his results in terms of observed axial ratios. This question of interpretation does not arise if the results are presented in terms of relative proportions of L.H. and R.H. bursts as has been done in the present paper.

A single eight-channel high-speed recorder was used to record the L.H. and R.H. components of individual noise bursts from all four polarimeters. A chart speed of 2 mm/sec and a recorder time constant of about 0.1 sec. was found to be satisfactory. General recordings were made separately at the slower chart speed of 6 inches/hour with a recorder constant of 0.25 sec. These latter observations could be made for longer periods of up to three and a half hours each side of transit because of the moderately broad reception pattern of the Yagis.

III. Identification

All of the observations were made at night when interference is at a minimum. Every period of observation was monitored by an observer and identification was by the aural monitoring technique. To be regarded as radiation from Jupiter the signal had to satisfy the following common-sense criteria which are based upon the discussion by Smith, A. G. and Carr (1959);-

1. Jupiter must be within the reception beam of the antenna.

2. The general recorder must show a deflection clearly visible above the background noise.

3. The signal must have the characteristic "swishing" sound of Jupiter radiation.

4. The signal must not tune out over a small bandwidth of about ± 0.25 Mc/s. This is an important distinction between Jupiter and a distant station which can sometimes sound very similar.

5. The signal must not be identifiable as of terrestrial origin. Static pulses, car ignition and power line radiation are the most common forms of interference and all of these have characteristic sounds quite different from Jupiter radiation. Additional checks using the beat frequency oscillator and the noise limiting circuitry are also possible. Use of the beat frequency oscillator makes station identification more certain and experience has shown that most Jupiter radiation can be detected with the noise limiter on while the terrestrial interference listed above is suppressed to a large extent.

These criteria were rigorously applied by all of the observers who made their assessment of each event at the time when it was recorded. The time duration of the event is entered on a data chart from which computer cards are prepared to produce histograms for the period of the observations. No attempt is made to read further activity information from the general records by any form of post-observation analysis. It is felt that this approach, which has been used in previous years, gives the most objective procedure possible with the equipment available. Hyde (1963) has recently discussed this problem of identification in some detail.

IV. Observations

Observations were made continuously from July 13 through December 5, 1963. These are summarized in Table 1. The corresponding occurrence probability histograms* are shown in Figure 2. Occurrence probability is defined as the ratio of the number of events occurring within a given 5° interval of System III central meridian longitude (λ_{III}) to the number of times when observation of that longitude was possible. This allows for occasions on which Jupiter was within the reception pattern of the antenna but, perhaps because of interference, could not be observed with any certainty.

Reception conditions were generally better at 18 Mc/s than at 16 Mc/s. The greater number of events recorded at 18 Mc/s (Table 1) does not, therefore, necessarily imply greater activity at this frequency than at 16 Mc/s. On some nights more than one event was observed at a single frequency.

A typical sequence of four sections of polarimeter record taken on August 11, 1963 is shown in Figure 3. In each record the L.H. sensitive channel is the uppermost of the pair of channels for each frequency. Reading downwards the frequencies are 16, 18, 22 and 26 Mc/s. Universal Time and λ_{III} marks are shown on each section of the record. An "X" marks some form of interference. A period of inactivity separated the two events during which, respectively, the first and the next three sections of record were taken.

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*The radio rotation period $9^h\ 55^m\ 29^s.37$, recommended by the International Astronomical Union for a provisional System III Ephemeris (U.S. Naval Observatory, (1962)), has been used throughout this paper.

In the first section, apart from a single L.H. burst at the beginning of the 18 Mc/s record, both 16 and 18 Mc/s channels show R.H. bursts with a few weaker R.H. bursts at 22 and a suggestion of R.H. activity at 26 Mc/s. In the second section traces begin to appear on the L.H. channels as well as the R.H. channels at 16 and 18 Mc/s although most of the bursts are still R. H. Very weak R.H. activity continues at 22 and 26 Mc/s. In the third section a number of L.H. bursts can be seen at 18 Mc/s while the 16 Mc/s bursts are weaker but still slightly R.H. Very weak R.H. activity continues at 22 and 26 Mc/s. In the fourth section the 16 Mc/s bursts are stronger but still R.H. whereas at 18 Mc/s both L.H. and R.H. bursts can be seen, in some cases separated by time intervals of only a few seconds. At 22 and 26 Mc/s there is no activity at all.

Another interesting section of record taken on September 13, 1963 is shown in Figure 4. In this record, the L.H. and R.H. displacements are very nearly equal at 18 Mc/s with the R.H. displacement slightly greater throughout. Similar traces can be seen at 26 Mc/s. Unfortunately, a recorder-amplifier fault rendered the 22 Mc/s R.H. channel inoperative during this event although it can be seen that the L.H. channel shows numerous bursts (and we may, perhaps, infer that the effect was the same at this frequency). At 16 Mc/s however, the polarization is quite strongly R.H. In the case where L.H. and R.H. displacements are almost equal the polarimeter system cannot determine whether almost linear or random polarization is being observed. As the R.H. channel predominates slightly throughout this type of event the bursts are listed as R.H. in Tables 2 through 6.

All of the high-speed records were analysed burst-by-burst and the relative proportions of L.H. and R.H. bursts were computed for each frequency. To be regarded as a separate burst at a given frequency one of the two pens must show a displacement of at least three times rms noise power and the pulse must be separated from adjacent pulses by a time of at least one second.

If the radiation is assumed to be completely polarized the axial ratio of the incident wave at the antenna can, of course, be calculated by comparison of the L.H. and R.H. recorder displacements as stated in Section II. This ratio, however, is not necessarily a very significant quantity unless some distinction is made between observed axial ratio and true axial ratio in the manner suggested by Dowden (1963) following the theory of Ellis and McCulloch (1963). It is unlikely that the terrestrial ionosphere could reverse the sense of polarization however else it might modify the radiation. For this reason it is thought preferable to present the general results of this analysis in terms of the general sense of polarization rather than in terms of axial ratio.

The results or the burst-by-burst analysis are summarized in Table 2. The most notable feature is the proportion of

L.H. bursts, 41% and 30% respectively, observed at 16 and 18 Mc/s when $300° < \lambda_{III} \leqslant 360°$. At other times lower, but still appreciable, proportions of L.H. bursts were observed at these frequencies. A few L.H. bursts were also recorded at 22 and 26 Mc/s mostly towards the end of the observing period. These were all recorded when $210° < \lambda_{III} \leqslant 300°$. Burst histograms for the period of the observations are shown in Figure 5. It should be noted that these histograms have been computed for 10° longitude intervals for all of the events recorded during 1963 which gave records suitable for analysis. Weak events in particular can often be detected but do not give high-speed records suitable for reliable analysis. The 22 and 26 Mc/s channels in Figure 3(c) are typical examples of this. The occurrence probability histograms in Figure 2 include all events regardless of whether or not useful polarization records were obtained.

As it appears that the polarization can change very considerably during an event, at least at the lower frequencies, it may be important to study individual events as well as long-term characteristics. For this reason, the burst characteristics of each event are shown for the four frequencies in Tables 3 - 6. Burst histograms for the events of August 11, 1963 are shown in Figure 6.

V. Summary of the General Characteristics of the Polarization

The general characteristics of the polarization during the period July 13 through December 5, 1963 may be summarized as follows:-

1. R.H. polarization predominated at all four frequencies but the proportion of L.H. bursts was greater at the lower frequencies.

2. At 16 and 18 Mc/s L.H. polarization was found to be associated with all three regions of λ_{III} but the greatest amounts were recorded when $300° < \lambda_{III} \leq 360°$.

3. With the exception of the 18 Mc/s event of December 5, 1963 and five weak L.H. bursts at 18 Mc/s on October 8, 1963, the polarization has never been exclusively L.H. at any frequency. L.H. bursts have always appeared mixed in varying proportions with R.H. bursts.

4. On some occasions, notably during September, both channels have shown almost equal displacements at a given frequency. The R.H. displacement has always been slightly greater than the L.H. in this case. This effect has been observed on several occasions at 18 Mc/s, to a lesser extent at 22 and 26 Mc/s but never at 16 Mc/s. Events of this type have been observed when $90° < \lambda_{III} \leq 140°$ and when $210° < \lambda_{III} \leq 300°$

5. A few L.H. bursts were observed at 22 and 26 Mc/s. Most of these appeared towards the end of the period of the observations.

6. An early tendency for L.H. bursts to appear at 16 and 18 Mc/s when $90° < \lambda_{III} \leq 140°$ (August 5, 1963; 16 Mc/s 30% L.H., 18 Mc/s 25% L.H., and July 21, 1962; 16 Mc/s 42% L.H., Barrow (1963)) was statistically "swamped" by the event of September 13 in which many bursts were observed at both frequencies practically all of which were R.H.

7. In terms of observed axial ratio, as defined by Dowden (1963) and by Carr et al. (1961), the values observed ranged from +1 (L.H. Circular) to -1 (R.H. Circular). On several occasions events were observed for which the average axial ratio was close to zero but slightly negative. This occurred most frequently at 18 Mc/s.

8. There has not been any obvious trend or systematic variation in the polarizations observed, either during an event or over the entire period, other than the association with λ_{III} mentioned under (2) above.

VI. Discussion

In a previous paper (Barrow (1962)) it was pointed out that if magneto-ionic effects on Jupiter are responsible for the general characteristics of the polarization observed on the Earth it should be possible to determine some of the ionospheric parameters on Jupiter by studying changes in polarization from one frequency to another. It it could be deduced uniquely that a critical frequency or gyrofrequency on Jupiter lies between two adjacent polarimeter frequencies the limits to the possible value would be quite narrow and would be virtually independent of possible terrestrial effects as it would not be necessary to rely on observed axial ratio measurements.

Consider a simple model of Jupiter with an ionospheric layer and symmetrical dipolar magnetic field. For a planet as large as Jupiter on which the sources of radiation are localized it does not seem unreasonable to expect that the magnetic field will extend spatially beyond the limits of the ionosphere. In this case it may be possible for radiation originating at a point where $f_H > f$ to escape in the extraordinary mode without encountering the region for which $f_H < f < f_x$. Increases in the magnetic field or decreases in the electron density will tend to facilitate this. It is generally agreed by most workers (NASA Conference (1962)) that the decametric radiation from Jupiter appears, in some manner, to be related to solar activity although the nature of the relationship is uncertain. In addition, Carr et al. (1961) have reported a long-term inverse sunspot correlation. As Jupiter events appear to correlate with terrestrial geomagnetic activity to some extent it is possible that not only Jupiter activity (as suggested by Carr et al. (1961)) but also daily polarization variations may be due to magnetic disturbances on Jupiter caused by the arrival of solar particles perhaps augmented by local scintillation effects. In this case we should expect to see a change in the proportion of L.H. polarization observed at lower frequencies soon after a period of enhanced solar-geomagnetic activity. It might also be expected that a long-term variation in polarization would occur corresponding to a gradual change in the electron density of the Jovian ionosphere associated with the sunspot cycle. The few L.H. bursts observed recently at 22 and 26 Mc/s might even be the beginning of such an effect. It will be interesting to see if such a trend developes to any extent as sunspot minimum approaches.

The foregoing ideas may be applied to the observations described in the previous sections of this paper. A careful examination of all the data shows that only in the case of events for which $300° < \lambda_{III} \leqslant 360°$ is it possible to obtain a unique result as there are insufficient events showing polarization changes for other values of λ_{III}. For the unique case, however, it appears that f_H can vary from a little below 16 Mc/s up to almost 18 Mc/s with a value of about 17 Mc/s implied most frequently.

This interpretation is at variance with some of the different theories which have been proposed to explain the origin and escape of the decametric radiation although it is not inconsistent with most of the experimentally observed characteristics of the radiation. In particular it requires, at least as far as radiation for which $300° < \lambda_{III} \leqslant 360°$ is concerned, that R.H. polarization corresponds to the ordinary magneto-ionic mode although this is not necessarily the case for other regions where the radiation might escape from the opposite hemisphere of Jupiter. It should be noted that the present discussion is concerned only with escape conditions and not directly with possible origin mechanisms. At the present state of knowledge the only argument which has been presented against this type of simple magneto-ionic interpretation is the fact that the occurrence probability histogram peaks become narrower towards higher frequencies (Franklin and Burke (1958)). However, this can also be explained as a statistical effect as suggested by Barrow (1962). It is not suggested that this simple interpretation gives any more than an approximation to the escape conditions on Jupiter but it does emphasize the arbitrary nature of almost any theory formulated from our present limited knowledge of the planet. Certainly any future theoretical work should be able to account for such variations in polarization as are reported here as well as those mentioned in Section I by other workers. The theory of Ellis and McCulloch (1963) attempts to do this; in a future paper, observed axial ratios will be calculated from the observations described here and compared with the predictions of the Doppler-shifted cyclotron theory.

It is possible, as Dowden (1963) has suggested, that histograms of L.H. and R.H. bursts may eventually indicate the relative longitudes of centers of magnetic activity on Jupiter. One difficulty with this approach, however, is that the radiation is recorded much less frequently when λ_{III} is close to 110° or 330° than when it is close to 245° and not every event yields bursts of sufficient intensity for a reliable analysis. It may, therefore, take more observations than can be obtained during a single apparition to provide convincing statistics for the histograms. It is doubtful if a slight change in the radio rotation period, as reported by Douglas and Smith, H.J. (1963), would seriously affect histograms compiled from two or three apparitions for this purpose.

Acknowledgements.

The author wishes to thank Mr. J. D. Merritt, Mr. G. M. Resch and Mr. E. J. Seykora for their help in the maintenance and operation of the equipment. The work was supported by the National Aeronautics and Space Administration, Grant No. NSG-224-61.

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List of Tables.

TABLE I

	16 Mc/s	18 Mc/s	22 Mc/s	26 Mc/s
No. of days observation	139	138	138	141
No. of events observed	22	34	19	14
No. of days on which events were observed	17	28	16	11
No. of events yielding records suitable for polarization analysis	15	23	12	11

Frequency in [illegible]/s	$90 < \lambda_{III} \leq 140$			$210 < \lambda_{III} \leq 300$			$300 < \lambda_{III} \leq 360$		
	Total Number of Bursts	% L.H.	% R.H.	Total Number of Bursts	% L.H.	% R.H.	Total Number of Bursts	% L.H.	% R.H.
16	211	5	95	497	10	90	249	41	59
18	532	3	97	1036	9	91	267	30	70
22	64	0	100	381	7	93	4	0	100
26	434	0	100	121	7	93	4	0	100

TABLE 2

16 Mc/s

Date 1963	$90 < \lambda_{III} \leq 140$ Total Number of Bursts	% L.H.	% R.H.	$210 < \lambda_{III} \leq 300$ Total Number of Bursts	% L.H.	% R.H.	$300 < \lambda_{III} \leq 360$ Total Number of Bursts	% L.H.	% R.H.
Aug. 5	10	30	70						
8				31	0	100			
11				70	3	97	54	0	100
30				72	0	100			
Sept. 13	201	4	96	130	17	83			
19				10	0	100	44	77	23
Oct. 28							97*	48	58
Nov. 2				24	92	8			
7							36	25	75
22							10	90	10
23				110	3	97*			
28				50	0	100	8	25	75
Totals	211	5	95	497	10	90	249	41	59

* Event continued to $\lambda_{III} = 4°$

TABLE 3

18 Mc/s

Date 1963	$90 < \lambda_{III} \leq 140$ Total Number of Bursts	% L.H.	% R.H.	$210 < \lambda_{III} \leq 300$ Total Number of Bursts	% L.H.	% R.H.	$300 < \lambda_{III} \leq 360$ Total Number of Bursts	% L.H.	% R.H.
July 25				20	0	100			
30				37	0	100			
Aug. 4				21	0	100			
5	35	25	75						
8				64	0	100			
11				233	1	99	111	42	58
30				82	0	100			
Sept. 11				16*	0	100			
13	497	2	98	186	0	100			
19				46	0	100	23+	0	100
22				15	0	100			
Oct. 8				5	100	0			
12				8	0	100			
28							68	18	82
Nov. 2				7	85	15			
7							33	0	100
22							22	86	14
23				161	1	99			
28				57	0	100	10	0	100
Dec. 5				78	100	0			
Totals	532	3	97	1036	9	91	267	30	70

* Occurred when $179 \leqslant \lambda_{III} \leqslant 182$

+ Event continued to $\lambda_{III} = 2°$

TABLE 4

22 Mc/s

Date 1963	$90 < \lambda_{III} \leq 140$ Total Number of Bursts	% L.H.	% R.H.	$210 < \lambda_{III} \leq 300$ Total Number of Bursts	% L.H.	% R.H.	$300 < \lambda_{III} \leq 360$ Total Number of Bursts	% L.H.	% R.H.
July 25				20	0	100			
30				2	0	100			
Aug. 4				28	0	100			
5	64	0	100						
8				106	11	89			
11				80	1	99	4	0	100
Sept. 13	*			78	0	100			
Oct. 8				7	85	15			
12				9	0	100			
Nov. 2				6	67	33			
23				45	9	91			
Totals	64	0	100	381	7	93	4	0	100

* One 22 Mc/s recorder amplifier developed a fault during this event which included about 150 bursts, most of which were probably R.H. The fault was corrected before the second event commenced.

TABLE 5

26 Mc/s

Date 1963	$90 < \lambda_{III} \leq 140$			$210 < \lambda_{III} \leq 300$			$300 < \lambda_{III} \leq 360$		
	Total Number of Bursts	% L.H.	% R.H.	Total Number of Bursts	% L.H.	% R.H.	Total Number of Bursts	% L.H.	% R.H.
July 25				2	0	100			
Aug. 4				23	0	100			
5	192	0	100						
8				14	0	100			
11				26	0	100	4	0	100
Sept. 13	242	0	100	2	0	100			
Oct. 8				13	0	100			
Nov. 2				5	20	80			
23				33	21	79			
Totals	434	0	100	121	7	93	4	0	100

TABLE 6

List of Figures.

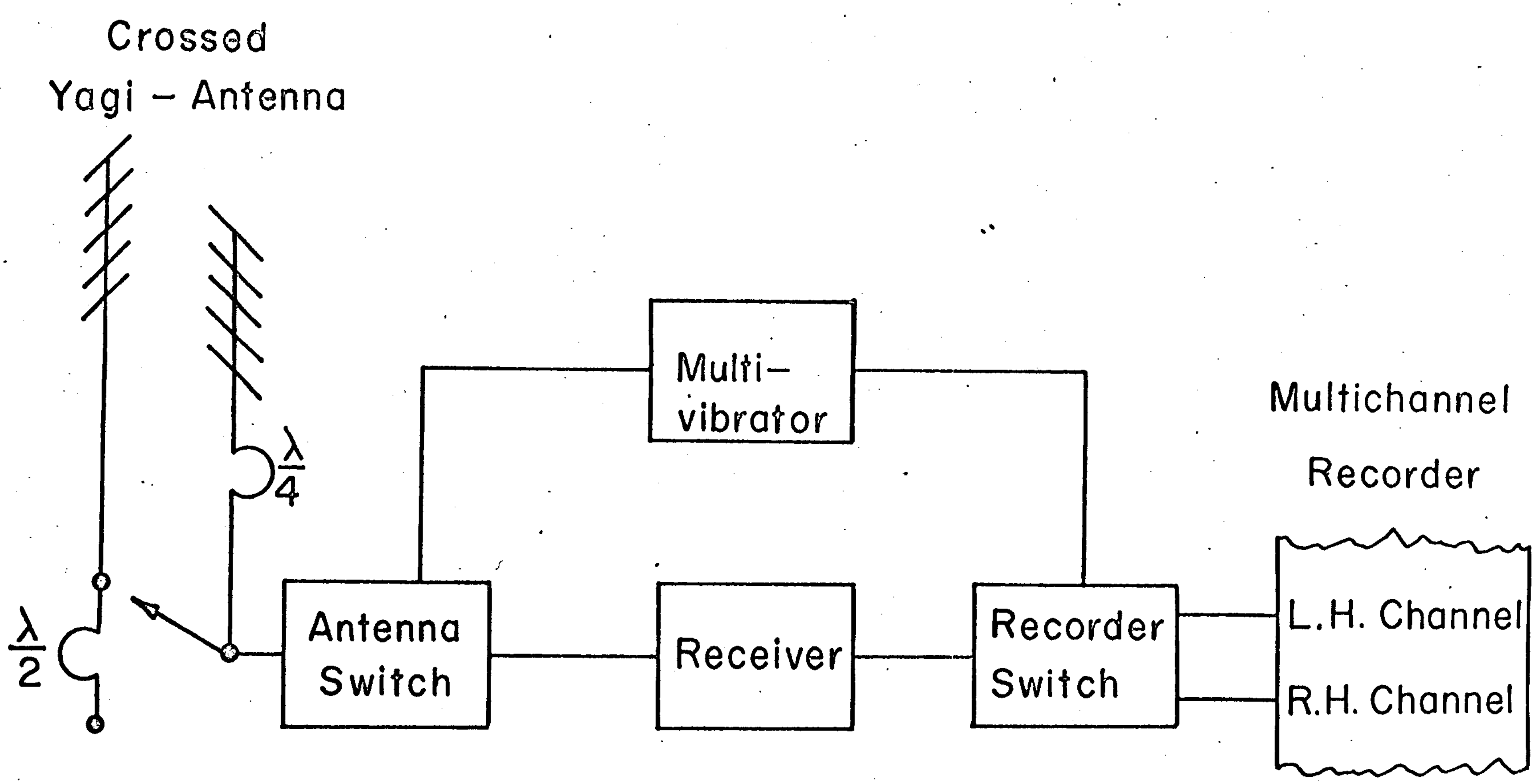


Figure 1. Schematic of the polarimeter system used at each frequency.

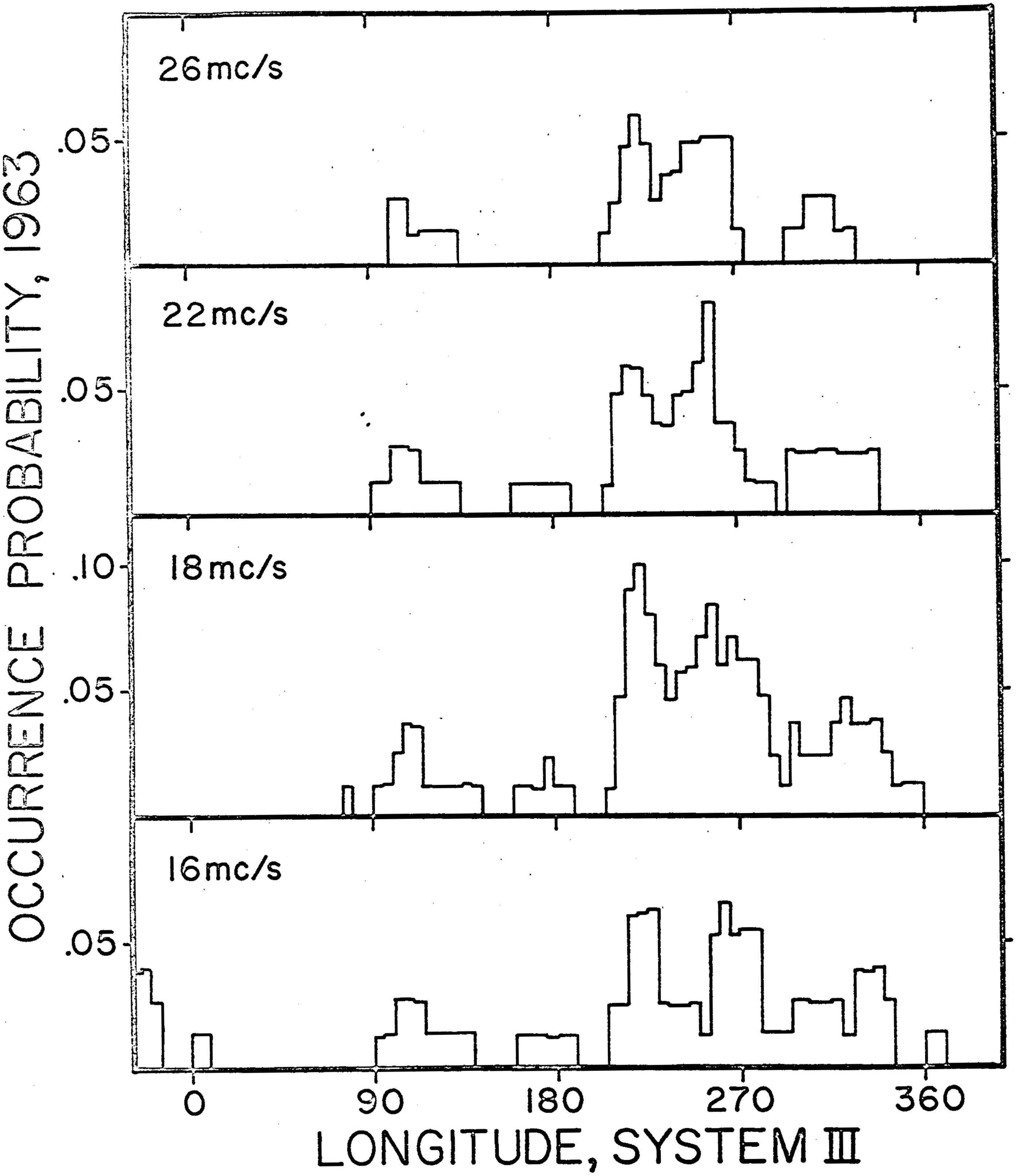
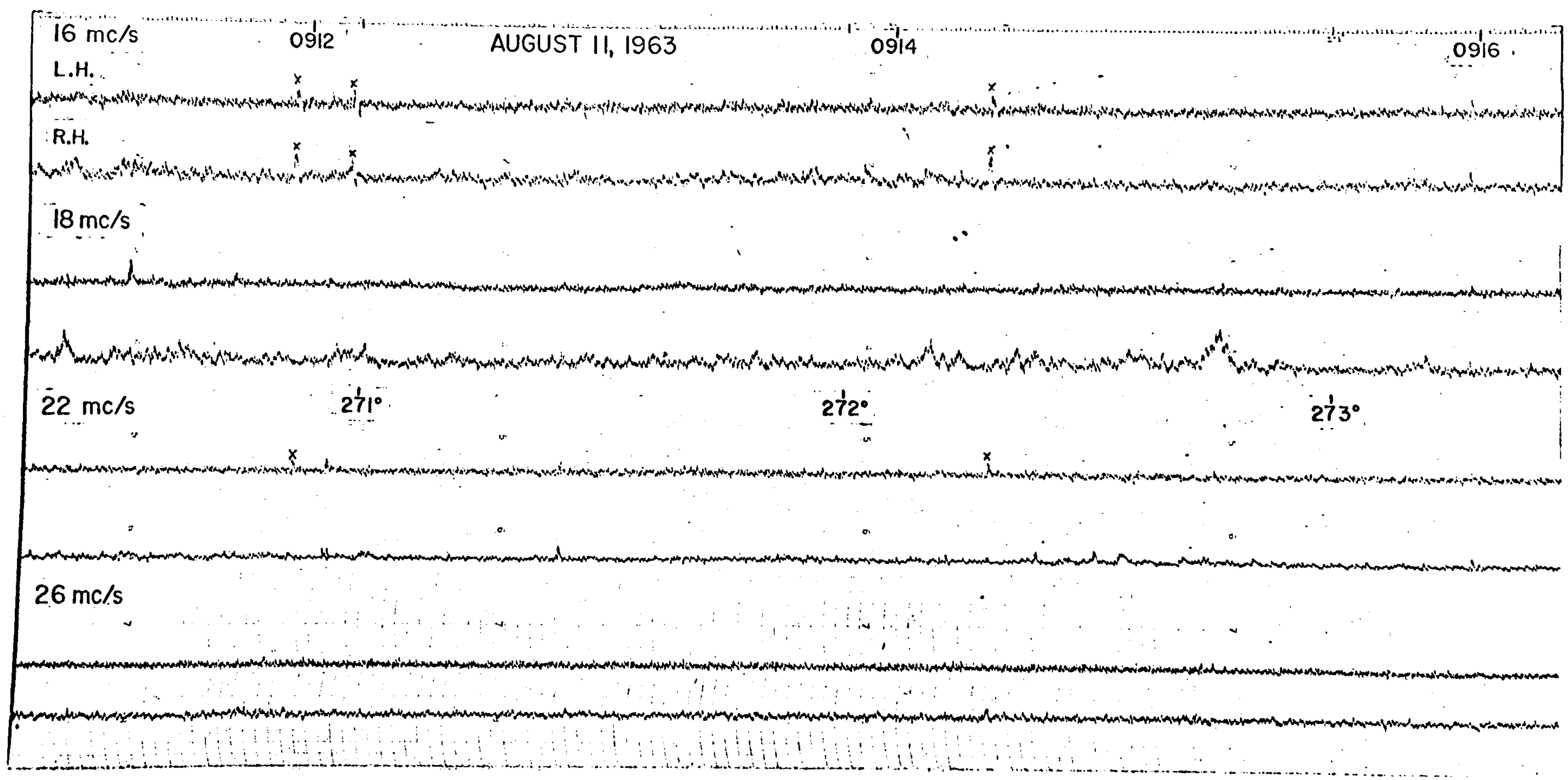
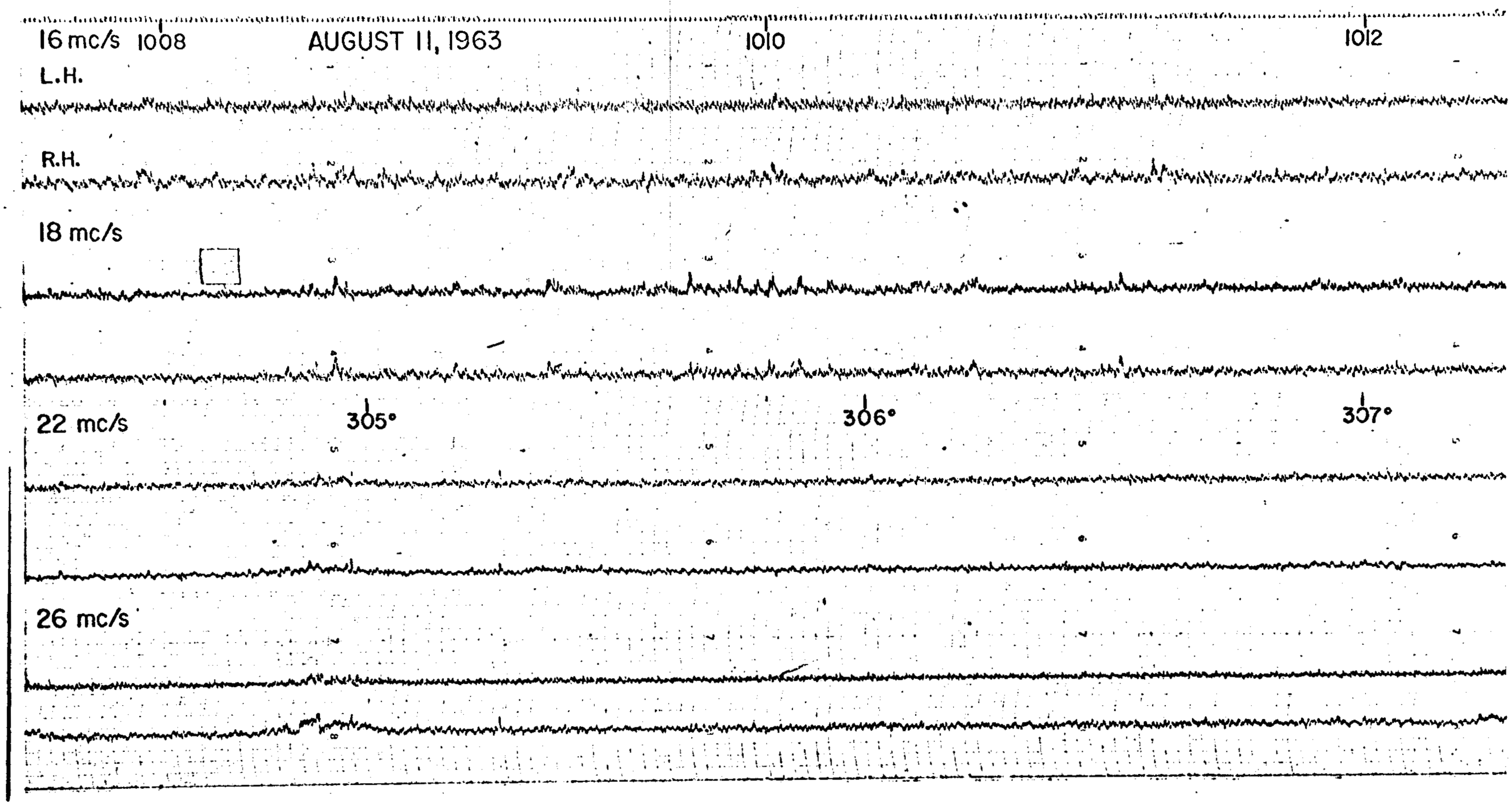


Figure 2. Histograms of occurrence probability of Jupiter radiation as a function of System III central meridian longitude for the period July 13 through December 5, 1963.

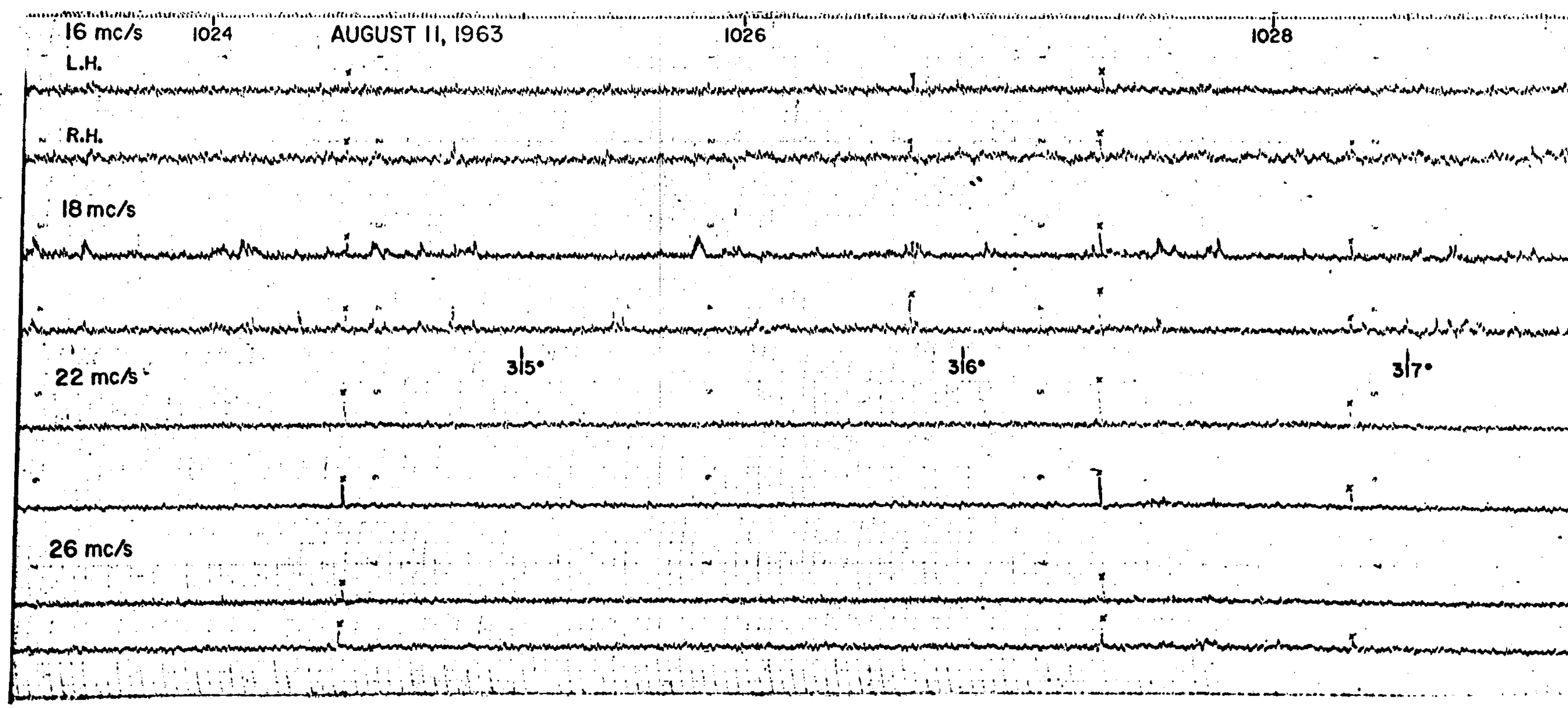


3(a)

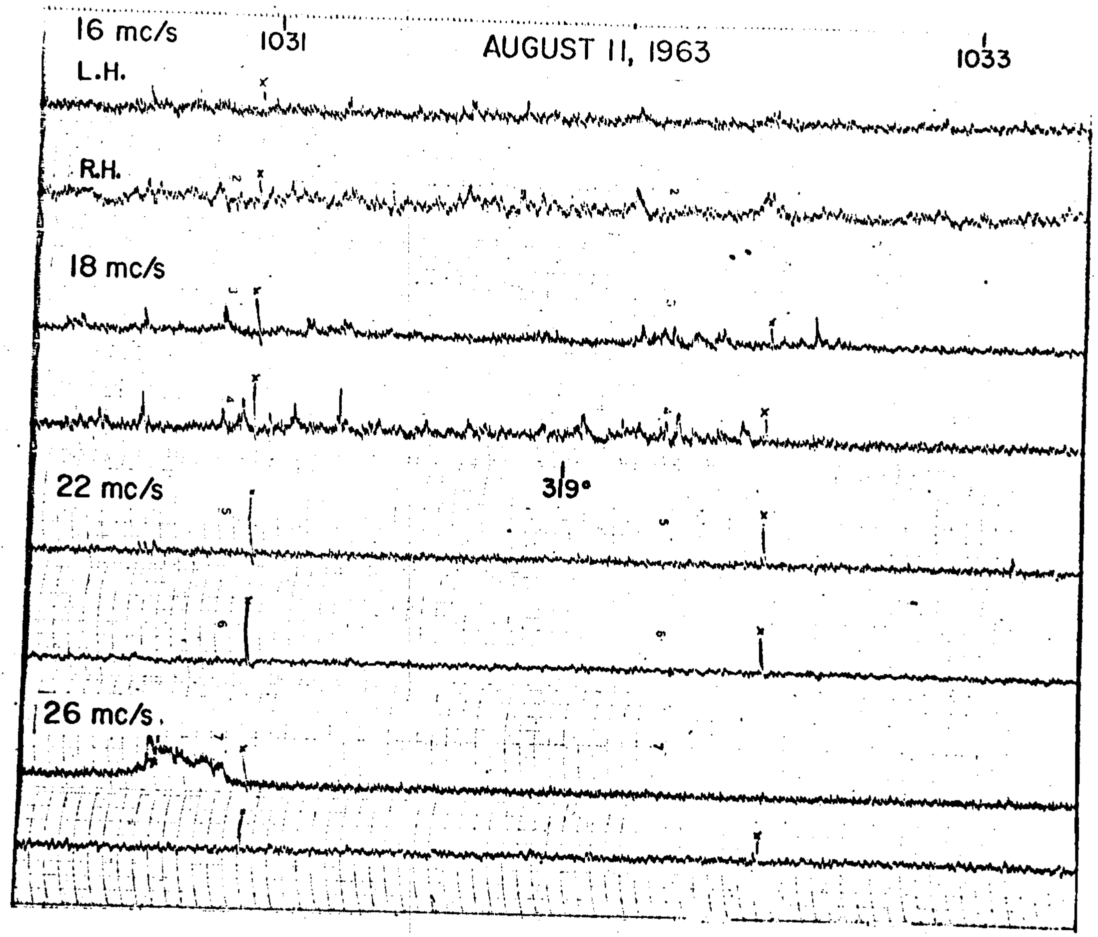
Figures 3(a)-(d). Typical sequence of polarimeter records taken on August 11, 1963.


16 mc/s 1008
AUGUST 11, 1963
1010
1012
L.H.
R.H.
18 mc/s
22 mc/s
305°
306°
307°
26 mc/s

3 (b)


16 mc/s
1024
AUGUST 11, 1963
1026
1028
L.H.
R.H.
18 mc/s
22 mc/s
3|5°
3|6°
3|7°
26 mc/s

3(c)



3(d)

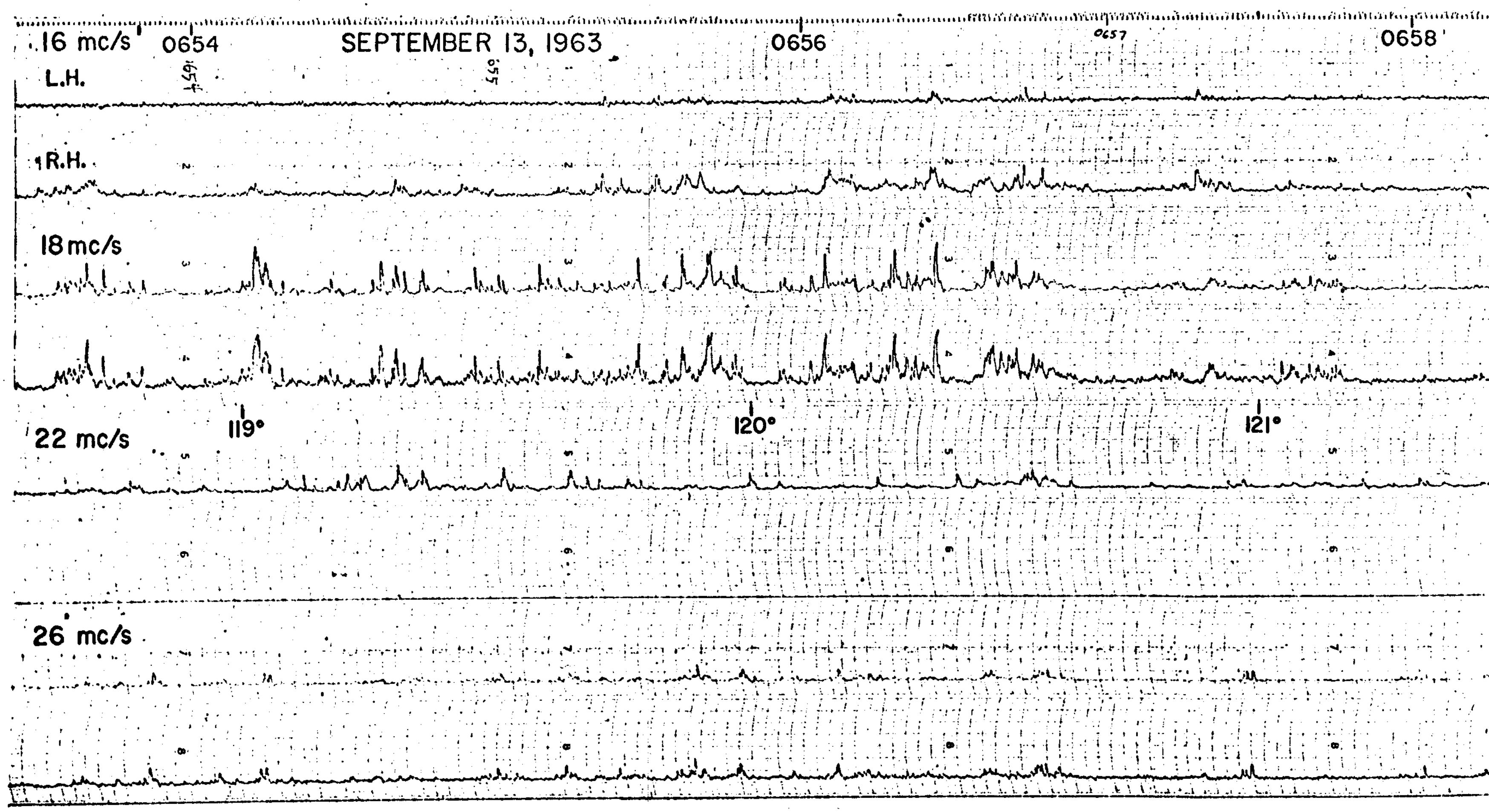


Figure 4. Polarimeter record taken on September 13, 1963.

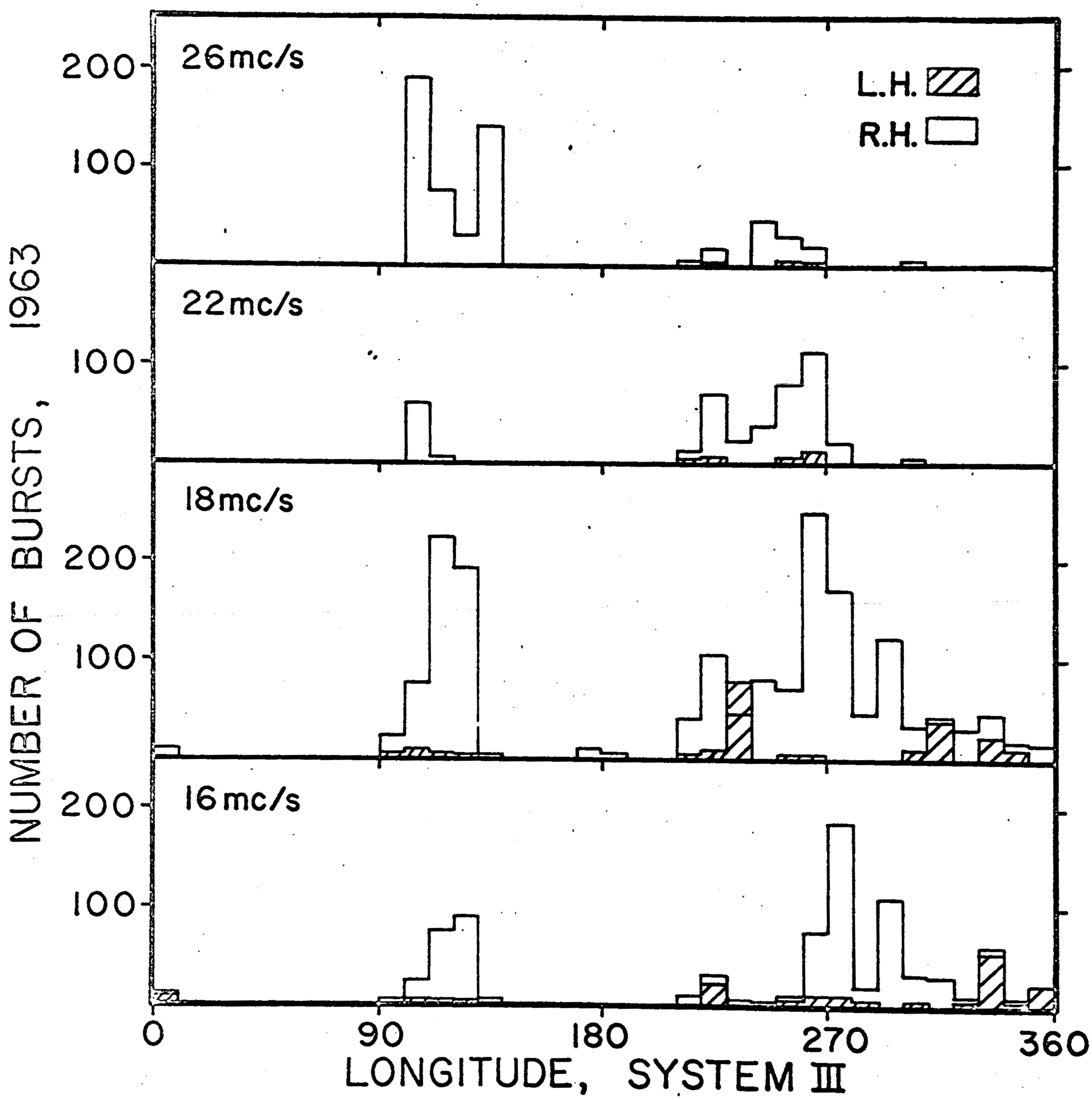


Figure 5. Histograms of numbers of L.H. and R.H. bursts as functions of System III central meridian longitude for the period July 13 through December 5, 1963 ($\Delta\lambda_{III}$ = 10°).

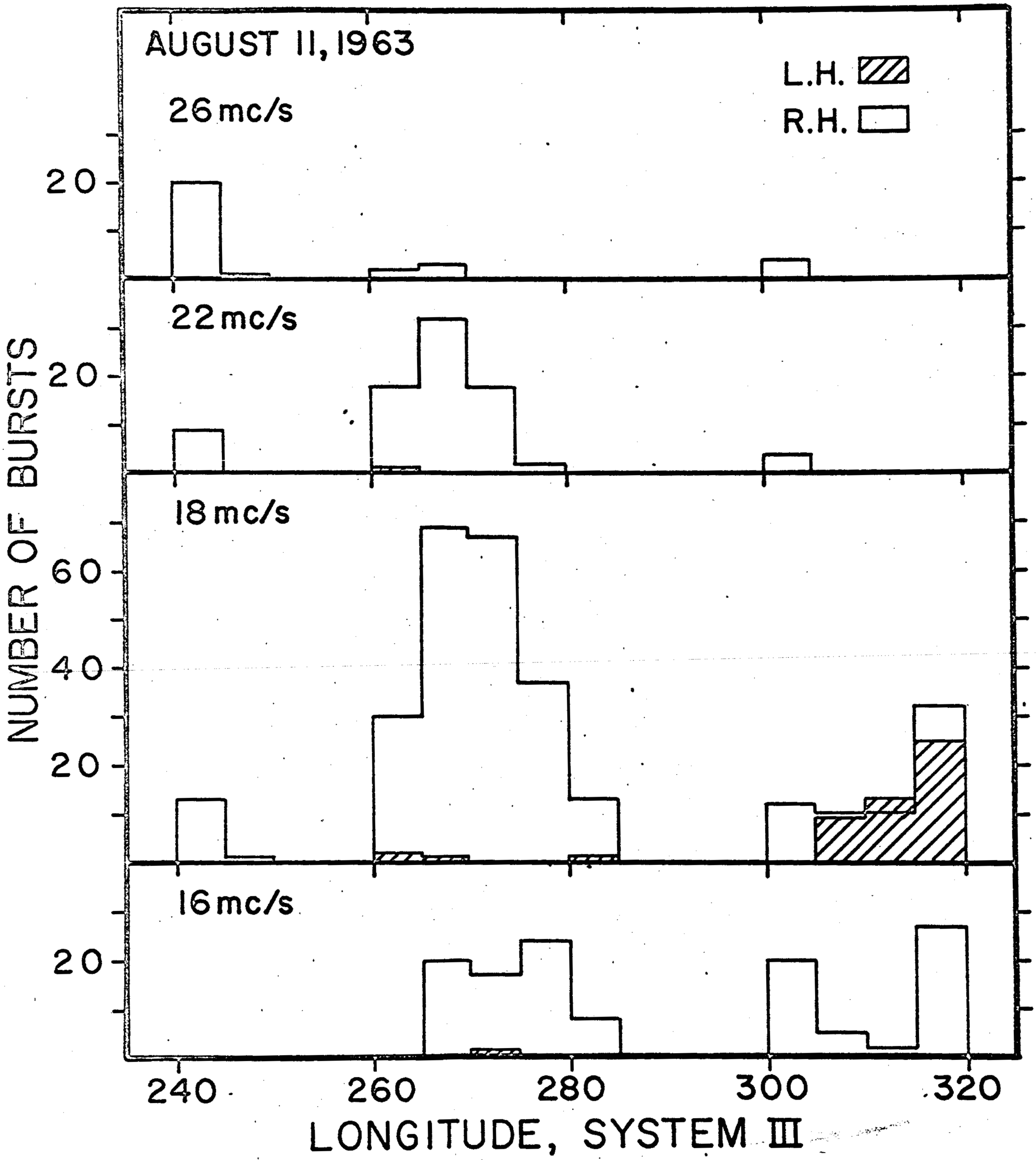


Figure 6. Histograms of numbers of L.H. and R.H. bursts as functions of System III central meridian longitude for the events of August 11, 1963 ($\Delta\lambda_{III} = 5°$).